

Universal properties in galaxies and cored DM profiles

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1 Abstract

In this paper I report the highlights of the talk: “Universal properties in galaxies and cored DM profiles”, given at: Colloquium Lectures, Ecole Internationale d’Astrophysique Daniel Chalonge. The 14th Paris Cosmology Colloquium 2010 “The Standard Model of the Universe: Theory and Observations”.

2 Highlights

The presence of large amounts of unseen matter in galaxies, distributed differently from stars and gas, is well established from rotation curves (RCs) which do not show the expected Keplerian fall-off at large radii (Rubin *et al.* 1980), but increase, remain flat or start to gently decrease according to a well organized pattern that involves an invisible mass component becoming progressively more abundant at outer radii and in the less luminous galaxies (Persic, Salucci & Stel 1996).

In Spirals we have the best opportunity to study the mass distribution: the gravitational potentials of a spherical stellar bulge, a dark halo, a stellar disk and a gaseous disk give rise to an observed equilibrium circular velocity

$$V_{tot}^2(r) = r \frac{d}{dr} \phi_{tot} = V_b^2 + V_{DM}^2 + V_*^2 + V_{HI}^2.$$

The Poisson equation relates the surface (spatial) densities of these components to the corresponding gravitational potentials. The investigation is not difficult: e.g. $\Sigma_*(r)$, the surface stellar density, is pro-

portional (by the mass-to-light ratio) to the observed surface brightness:

$$\Sigma_*(r) = \frac{M_D}{2\pi R_D^2} e^{-r/R_D}$$

and then

$$V_*^2(r) = \frac{GM_D}{2R_D} x^2 B\left(\frac{x}{2}\right),$$

where M_D is the disk mass, R_D the disk length-scale and $B(x)$ a combination of Bessel functions.

Dark and luminous matter in spirals are coupled: at any galactocentric radii R_n measured in terms of disk length-scale $R_n \equiv (n/5) R_{opt}$ ($R_{opt} = 3.2R_D$), there is a *Radial* Tully-Fisher relation (Yegorova & Salucci 2007), i.e. a relation between the local rotation velocity $V(R_n)$ and the total galaxy luminosity: $M_{band} = a_n \log V_n + b_n$. Spirals present universal features in their kinematics that correlate with their global galactic properties (PSS and Salucci *et al.* 2007).

This led to the discovery, from 3200 individual RCs, of the “Universal Rotation Curve” of Spirals $V_{URC}(r; L)$ (see PSS and Fig. 1), i.e. a function of galactocentric radius r , that, tuned by a global galaxy property (e.g. the luminosity), well reproduces, out to the virial radius (Shankar *et al.* 2006), the RC of any spiral (Salucci *et al.* 2007). V_{URC} is the observational counterpart to which the circular velocity profile emerging in cosmological simulations must comply (link to www.youtube.com/user/dvd5film#p/a/u/1/YcgafVb-WJI for a 3-D visualization of the URC).

In the same way of individual RCs, it underlies a mass model that includes a Freeman disk and a DM

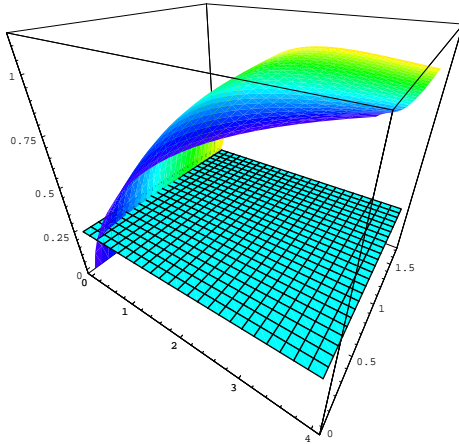


Figure 1: The URC. The circular velocity as a function of radius (in units of R_D and out to $4 R_D$) and luminosity (halo mass). See Salucci *et al.* 2007 for details and for the URC out to the virial radius.

halo with a Burkert profile

$$\rho(r) = \frac{\rho_0 r_0^3}{(r + r_0)(r^2 + r_0^2)}.$$

r_0 is the core radius and ρ_0 the central density, see Salucci & Burkert 2000 for details. We obtain the structural parameters ρ_0 , r_0 , M_D by χ^2 fitting the URC and a number of individual RCs. As result a set of scaling laws among local and global galaxy quantities emerges (see Fig. 2).

These scaling laws indicate (Salucci *et al.* 2007) that spirals have an Inner Baryon Dominance region where the stellar disk dominates the total gravitational potential, while the DM halo emerges farther out. At any radii, objects with lower luminosities have a larger dark-to-stellar mass ratio. The baryonic fraction in spirals is always much smaller than the cosmological value $\Omega_b/\Omega_{matter} \simeq 1/6$, and it ranges between 7×10^{-3} to 5×10^{-2} , suggesting that processes such as SN explosions must have removed a very large fraction of the original hydrogen. Smaller spirals are denser, with their central density spanning 2 orders of magnitude over the mass sequence of spirals.

To assume a cored halo profile is obligatory. It is

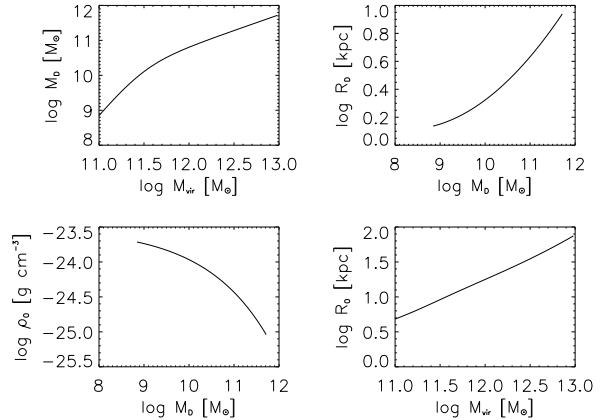


Figure 2: Scaling relations between the structural parameters of the dark and luminous mass distribution in spirals.

well known that Λ CDM scenario provides a successful picture of the cosmological structure formation and that large N-body numerical simulations performed in this scenario lead to the commonly used NFW halo cuspy spatial density profile. However, a careful analysis of about 100 high quality, extended and free from deviations from axial symmetry RCs has now ruled out the disk + NFW halo mass model, in favor of cored profiles (e.g. Gentile *et al.* 2004, 2005, Donato *et al.* 2004, Spano *et al.* 2007, de Blok 2008, Kuzio de Naray *et al.* 2008).

The mass modelling in dSph, LSB and Ellipticals is instead still in its infancy. However, data seem to confirm the pattern shown by in spirals (Gilmore *et al.* 2005, Walker *et al.* 2010, Nagino & Matsushita, 2009).

Regarding the structural properties of the DM distribution a most important finding is that the central surface density $\propto \mu_{0D} \equiv r_0 \rho_0$, where r_0 and ρ_0 are the halo core radius and central spatial density, is nearly constant and independent of galaxy luminosity. Based on the co-added RCs of ~ 1000 spiral galaxies, mass models of individual dwarf irregular and spiral galaxies of late and early types with high-quality RCs and on galaxy-galaxy weak lensing signals from a sample of spiral and elliptical galaxies, we find that:

$$\log \mu_{0D} = 2.15 \pm 0.2$$

in units of $\log(M_\odot \text{ pc}^{-2})$. This constancy transpases the family of disk systems and reaches spherical systems. The internal kinematics of Local Group dwarf spheroidal galaxies are consistent with this picture. Our results are obtained for galactic systems spanning over 14 magnitudes, belonging to different Hubble Types, and whose mass profiles have been determined by several independent methods. Very significantly, in the same objects, the approximate constancy of μ_{0D} is in sharp contrast to the systematical variations, by several orders of magnitude, of galaxy properties, including ρ_0 and central stellar surface density, see Fig. 3.

The evidence that the DM halo central surface density $\rho_0 r_0$ remains constant to within less than a factor of two over fourteen galaxy magnitudes, and across several Hubble types, does indicate that this quantity is perhaps hiding the physical nature of the DM. Considering that DM haloes are (almost) spherical systems it is surprising that their central surface density plays a role in galaxy structure. Moreover it is difficult to understand this evidence in an evolutionary scenario as the product of the process that has turned the primordial cosmological gas in the stellar galactic structures we observe today. Such constancy, in fact, must be achieved in very different galaxies of different morphology and mass, ranging from dark matter-dominated to baryon-dominated objects. In addition, these galaxies have experienced significantly different evolutionary histories (e.g. numbers of mergers, significance of baryon cooling, stellar feedback, etc).

The best explanation for our findings relays with the nature itself of the DM, as it seems to indicate recent theoretical work (de Vega *et al.* 2009, 2010.) In Warm Dark Matter scenario, it is quite possible, for certain values of the particle mass, to form cored DM virialized structures (de Vega *et al.* 2010).

The results obtained so far indicate that the distribution of matter in galaxies is a benchmark for understanding the dark matter nature and the galaxy formation process (at darkmattergalaxies.selfip.org the reader could be interested in an initiative that strongly takes this point of view). In particular, the universality of certain structural quantities and the dark-luminous coupling of the mass distributions

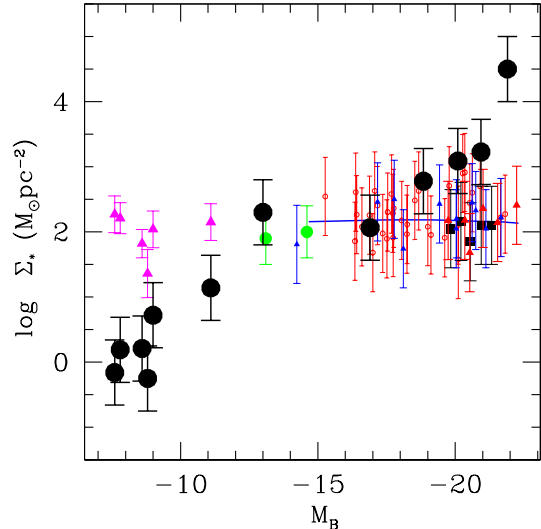


Figure 3: Dark matter central surface density in units of $M_\odot \text{ pc}^{-2}$ as a function of galaxy magnitude, for different galaxies and Hubble Types. As a comparison, we also plot the values of the same quantity relative to the stellar component (big filled circles).

seem to bear the direct imprint of the Nature of the DM (Donato *et al.* 2009, Gentile *et al.* 2009).

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